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Battlefield visualization and intelligent agents decis support

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Index Terms:
data visualisation decision support systems military computing software agents 3D 3D visualization toolkit battlefield visualization combat doctrine decision support syst intelligent agents military operations prefixed action-rules war virtual scenario

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Battlefield Visualization and Intelligent Agents Decision Support

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Abstract. This paper describes a decision support system for military operations based on intelligent agents dedicated to the planning and shaping activities. The system has a 3D visualization toolkit for the modeling of the war virtual scenario, which is represented by a 3D mesh using a height map of the actual battle space. The intelligent agents approach is used to support the commanders' decisions in conformity with a known combat doctrine. Each troop is designed as an agent, where its actions are described as a set of prefixed action-rules.

1 Introduction

When fighting a battle, commanders must analyze and understand both current and future combat scenarios in order to make strategic decisions, and also, plan and evaluate the force movements. Those activities are usually accomplished with paper maps of the battle area, placed under sheets of acetate. This paper focuses the battlefield visualization problem.

2 Terrain Modeling

One of the greatest challenges of the battlefield visualization problem is related to the acquisition cartographic data, and displaying it [1]. Height maps are used to create the digital terrain model. A regular grid based algorithm divides a large terrain into smaller patches using a recursive quadrantal routine. The well-known technique described by Röttger [3] was improved in order to reduce the number of triangles. Röttger would divided the triangulated height field into a balanced quadtree to avoid cracks. The implemented method just divides the two tree nodes, which have a common edge with the more refined node. The remaining one is not divided. This approach reduces 8.738% the number of rendering triangles of Röttger method. Finally, a raster image of the actual battle area is mapped over the modeled surface applying texture procedures. This guarantees a virtual reality model where all the paper map information is available, like the existing mountains, rivers and roads around the battle area [2].

3 Troops Symbology

The criteria for representing the troops over the virtual battle space were based on the cartographic 2D simbology manual of the Brazilian Army. 3D objects were needed in order to be visible from oblique angles. For this reason the 2D ones were extruded into cubes, pyramids and spheres. The 3D unity objects might also have some pieces of representation, composed by characters, surrounding it. These characters can also become occluded. So, whenever the commander navigates through the scenario, all the text surrounding the 3D object rotates in order to keep facing the commander viewpoint.

4 Intelligent Agents

The agent engine is supplied by data extracted from the intelligence reports received from the field. These reports are related to the seven interconnected knowledge groups. At first, agents can calculate its ability to engage on combat, during the day and night maneuvers. This is an absolute value, which means that it does not take into consideration the neighboring unities. The pool of agents evaluates the battlefield situation according to a knowledge base, and the troops receive a score for each of its knowledge groups. Then a report to a second kind of entity is made, which is responsible to consolidate the data and compute the relative power of combat. This value is a quantitative number, which strict describes the relationship between the enemy fighting ability and allied one.

5 Conclusion

The implemented system has proved to be efficient when applied over the training of military troops. The mesh simplification is essential to allow the use of the application under poor graphical stations .The use of intelligent agents offers a tool for both the analysis and the efficiency evaluation of troops actions.

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Locating forward opportune landing sites using spe images from satellites

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Abstract:
The ability of future combat airlifters to deliver cargo into short, austere oppo landing sites which are very close to operating field units is expected to great the effectiveness of the US warfighter. But how do we find and select those si quickly-changing **battle** scenario? The use of spectral **image** data from satell EarthWatch as the medium for identifying opportune landing sites is the conc interest and is described. A study was performed to explore the feasibility anc requirements for this concept. The study's **objectives** were two-fold: (1) eva demonstrate airlifter value; and (2) evaluate and demonstrate opportune lanc selection concept feasibility. Spectral data was collected in several **image** res selected areas within the US. Potential opportune landing sites were selected areas and the selection was refined based on higher resolution spectral **imag** surveys were used to grade the accuracy of selection. The number of opportu sites (as short as 600 feet) relative to traditional runway lengths was determi compared

Index Terms:
airports infrared imaging military aircraft remote sensing surveillance EarthWatch accuracy of selection combat airlifters data requirements forward opportune landing : location landing site selection concept feasibility quickly-changing battle scenario sit spectral images from satellites thermal maps

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Locating Forward Opportune Landing Sites

using

Spectral Images

from

Satellites

Richard Botschner
Ball Aerospace & Technologies Corporation

ABSTRACT

The ability of future combat airlifters to deliver cargo into short, austere opportune landing sites which are very close to operating field units is expected to greatly improve the effectiveness of the US warfighter. But how do we find and select those sites in a quickly-changing battle scenario? The use of spectral image data from satellites such as EarthWatch as the medium for identifying opportune landing sites is the concept of interest and is described herein.

Ball Aerospace & Technologies Corporation (BATC) performed a study to explore the feasibility and data requirements for this concept. The study's objectives were two-fold:

- Evaluate and demonstrate airlifter value; and
- Evaluate and demonstrate opportune landing site selection concept feasibility.

Spectral data was collected in several image resolutions for selected areas within the US. Potential opportune landing sites were selected across large areas and the selection was refined based on higher resolution spectral images. Site surveys were used to grade the accuracy of selection. The number of opportune landing sites (as short as 600 feet) relative to traditional runway lengths was determined and compared.

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BACKGROUND

This paper summarizes Ball Aerospace & Technologies Corporation's (BATC) work effort under contract 6XY004217-9 in support of McDonnell Douglas Aerospace Corporation (MDC), Long Beach, CA, in their development of advanced technology transport aircraft. Other studies focusing on the use of remote sensing to identify opportune landing sites could not be identified.

DATA AND DATA PROCESSING REQUIREMENTS

An opportune landing site must support the performance characteristics, the performance limitations, and the associated takeoff/landing profiles of the aircraft using the landing site. The aircraft capabilities and limitations translate into attributes that describe the required physical characteristics of the ground and surrounding area adjacent to the opportune site. These physical characteristics in conjunction with area themes, were used during the opportune site selection process to logically select areas that could support a useful runway.

Table 1. Aircraft Landing Requirements

Aircraft of Interest	Minimum Landing Surface Length (ft)	Minimum Landing Surface Width (ft)	Minimum Runway Width (ft)	Minimum CBR for 40 Passes
C-130 (Line & Special Pilot)	3500	60	130	4.1
C-130 (Special Pilot)	2,500	60	130	4.1
SSTOL (Line Pilot)	600	40	130	4.5

Note: A CBR of 4.1 supports landing on high plasticity clay, turf and harder surfaces

Table 1 shows the aircraft landing requirements for three aircraft/pilot variations that include a Super Short Take-Off and Landing (SSTOL) Tiltwing aircraft flown by an inexperienced pilot (Line Pilot), a C-130 aircraft flown by an experienced pilot (Special Pilot), and a C-130 aircraft flown by an inexperienced pilot (Line Pilot). The requirements apply to sea-level, standard day for a 3.0G aircraft load configuration.

The California Bearing Ratio (CBR) measures the hardness of an unprepared earth bearing surface. CBR is a function of the surface and subsurface mineral content, water content, and soil compression properties as well as the number of aircraft landings/takeoffs (passes) that it will support.

The minimum runway width includes a flat portion on either side of a runway surface and an obstacle clearance slope on either side of the flat width. The minimum runway width allows for lateral movement of the aircraft prior to touchdown and the presence of vertical obstructions (crops, bushes, signs, buildings, etc.) on either side of the runway.

BATC estimated the minimum CBR for 40 passes using derived CBRs for 1 pass (provided by MDC engineers) and a relationship derived from a formula presented in a Government report, [1]. The derived relationship is:

$$CBR_X = [1+(x/100)(Coverage-1)]^{1/6}\, CBR_1$$

where CBR_X is the CBR for X number of passes and coverage refers to the number of times every point in the area is passed over by an aircraft wheel. Coverage is a function of the number of wheels and the wheel sizes.

Other considerations include the maximum slope of the landing surface and the maximum ground roughness. The maximum slope of the landing surface applies to the incline/decline of the landing surface in the direction of the aircraft. A 5° slope was assumed for this analysis. Maximum ground roughness was not considered during the selection of opportune landing sites due to the limited resolution of available data.

Areas Within the US Selected for Evaluation

The initial goal of the feasibility study was to select areas within the continental US that were most like four international regions of interest. This strategy was altered due to the scarcity of affordable multispectral data. The final areas of interest were chosen to make the most out of what was available. They include three 100-square mile scenes: The Black Hills near Spearfish, SD; a portion of Los Angeles, CA north of Palos Verdes; and an area north of Salinas, CA.

Spectral Image Data Requirements

The type and number of categories that can be extracted from an image or map depend on the amount of detail the map creator has available (and uses) to describe the location's features. Higher resolution data makes it easier to identify landing obstacles. Using 10-meter resolution data, the analyst is able to identify a single large tree and can identify the existence of buildings and houses. Using 100-meter data, the analyst can only identify a forest or large area of trees or flag cells as commercial or industrial areas. The 1-meter data would allow a more direct identification of obstacles to landing, since many obstacles causing extensive damage to an aircraft could easily approach 1-meter dimensions.

BATC used multispectral data of various resolutions in a progression to perform the analysis in each area of interest. The data in the progression included 100-meter seven-band Landsat™ satellite data and 1- to 3-meter four-band data collected by a commercially flown airborne sensor system. The bands covered the visible red, blue, green range; the near-infrared, short-wave infrared, and long wave infrared.

Multi-band composite images were used to create a true color image composed of the blue, green, and red bands or a false-color image composed of a variety of bands (visual or non-visual) for determining areas populated with vegetation or for determining water and road boundaries.

Features or themes were extracted from images to either accept or reject a pixel as a suitable landing attribute. The themes included seven vegetation, three hydrography, seventeen geology, five land usage, and two man-made obstacle classifications. A truth table was charted using true or false notation to indicate whether the classified pixel supported or precluded landings, respectively. The assignment of T or F for several themes was dependent on ground moisture content. In these cases, the condition, wet or dry, was noted. For example, a bare soil field will support landing during dry conditions but will

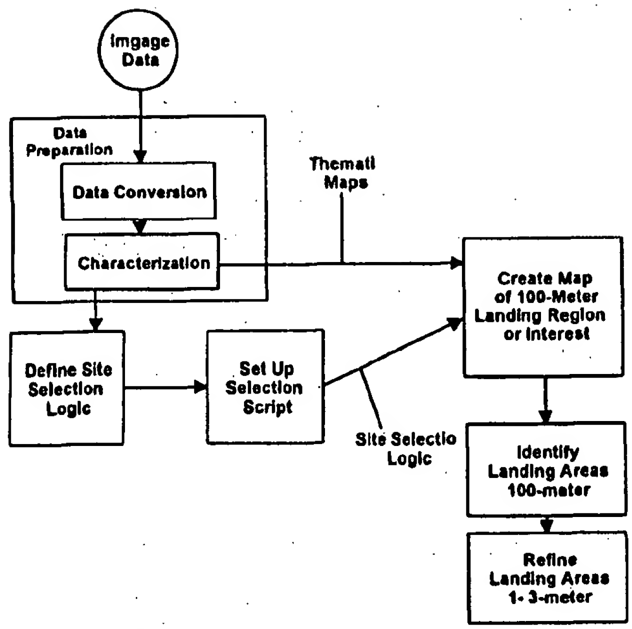


Fig. 1. Site Selection Analysis Process

not support landings when the soil turns to mud. The weather dependencies could be considered by the mission planners as one of the last factors for selecting a suitable landing area just hours prior to the planned sortie.

SELECTION OF OPPORTUNE LANDING SITES

Opportune landing areas were selected across large areas for several runway length variations and the selection was refined based on higher resolution spectral images.

Figure 1 outlines the site selection analysis process. Several input variations were chosen to support the evaluation of data resolution requirements, the evaluation of SSTOL Tiltwing (Line Pilot) concept benefits over other airlifter aircraft, and the feasibility of the opportune site selection concept. The image data shown as an input to the overall process includes the 100-meter, 3-meter and 1-meter resolutions for each of the three areas of interest. Data preparation was performed on images for each of the three data resolutions. Site selection logic was developed to automatically process each of the three large 100-square mile 100-meter resolution data images in order to create the initial landing regions of interest.

BATC determined the number of landing site areas within each of the 100-square mile areas of interest (the Black Hills, Los Angeles, and Salinas) for three runway length variations. The runway variations of 600 feet, 2500 feet, and 3500 feet were chosen to represent the typical runway requirements for SSTOL Tiltwing (Line Pilot), C-130 (Special Pilot), and C-130 (Line Pilot) cargo aircraft, respectively. BATC used the Potential Landing Site maps and the following criteria to count the number of landing site areas:

- At least 2 contiguous blocks (one by at least two landable pixels) were required to make up a 600-ft runway length and a 130-foot runway width landing area;
- At least 8 contiguous blocks (one by at least eight landable pixels) were required to make up a 2500-foot runway length and a 130-foot runway width landing area;
- At least 11 contiguous blocks (one by at least 11 landable pixels) were required to make up a 3500-foot runway length and a 130-foot runway width landing area.

BATC used 1- and 3-meter images to refine the site selection process. A sample of sites, chosen based on 100-meter data resolution images, was revisited using features that were extracted from the higher resolution images. Obstacles, both man-made and natural, were the primary focus. An opportune site selected by the 100-meter data was declared acceptable if no 1- or 3-meter pixels within the landing area contained non-landable criteria; acceptable with site preparation if 1 to 20 1-meter pixels within the landing area contained non-landable criteria; and non-acceptable if any 3-meter or more than 20 1-meter pixels contained non-landable criteria. Figure 2 illustrates the refinement process.

SITE EVALUATION

Site surveys were used to grade the accuracy of selection for a small sample of sites. Eight opportune

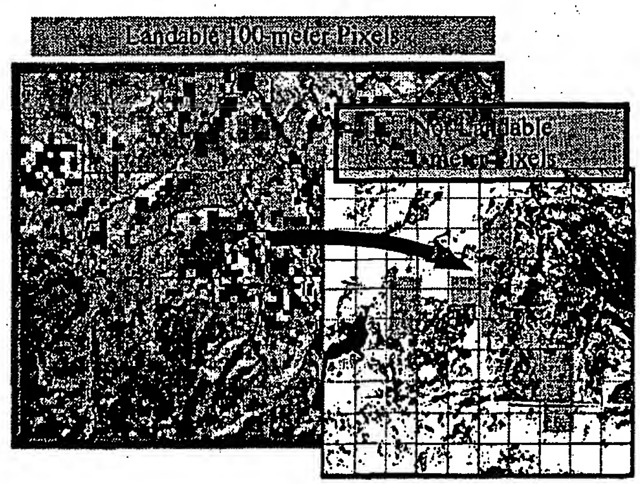


Fig. 2. Site Selection Refinement

landing areas in the Black Hills, and several others in the California areas of interest were surveyed to evaluate and rate the goodness of selection. The evaluation of selected opportune landing sites was primarily qualitative and did not utilize a qualified surveyor. Four tools and a digital camera were used to assist the site evaluation team. The tools included a hand-held GPS receiver,

a 200-foot ruler used for measuring ground distances, and a compass. The camera was used to record a visual image of the areas surveyed.

An evaluation team visited each of the pre-selected surveyed landing areas and characterized the weather conditions, ground moisture content, and the growing season based on visual observation. After measuring the center coordinates of the landing site using a GPS receiver, the team rated the goodness of selection based on eight attributes: location, which was measured using the GPS receiver; size, which was measured using either a visual observation or the 200-foot ruler if the size was questionable; slope; ground hardness; the presence of man-made obstruction; and the presence of three classes of natural obstructions, vegetation, earth or rock, and ruts, creeks or swells. Using pre-defined criteria, the team rated and documented each attribute as either acceptable, acceptable with some site preparation, or unacceptable.

The on-site survey of the eight sites in the Black Hills region was conducted on the 6th and 7th of November, 1996. The weather conditions were dry but cold. The ground was generally snow covered with the deepest snow in low-lying areas. The snow made the ground assessment more difficult, since the pre-survey analysis used non-snow covered images where rocks, ruts and swells were clearly visible. However, some areas of the ground were uncovered enough to recognize the general features which consisted of pasture grass with a scattering of flat and rough rocks ranging in size, with the largest several feet across. The area was populated by cattle farms and contained many small dry creeks and fence lines. Heavy tree areas were aligned along creek banks.

The survey team eliminated four out of the eight opportune landing areas in the Black Hills identified by the 100-meter images. These four opportune landing areas were assessed to be unacceptable under all conditions. That is, site preparation would not be practical. Two additional sites of the remaining four were considered acceptable following site preparation.

CONCEPT FEASIBILITY

Following the site visit, BATC analyzed the results to assess the probability of correct selection and the "goodness-of-selection factor" for each of three pixel resolutions; 1-meter, 3-meter, and 100-meter.

BATC grouped sites into one of three categories: useful landing sites with and without preparation; useful landing sites without site preparation; and non-useful landing sites. The grouping was based on the rating of the man-made and natural obstructions where acceptable, marginal and un-acceptable equated to: useful landing sites with and without preparation; useful landing sites without site preparation; and non-useful landing sites, respectively. The number of sites identified by each data resolution case and the resultant probability of correct selection is shown in Table 2.

COMPARISON OF AIRCRAFT ALTERNATIVES — STATISTICAL RESULTS

BATC considered three statistical metrics to compare differences between the variations in runway

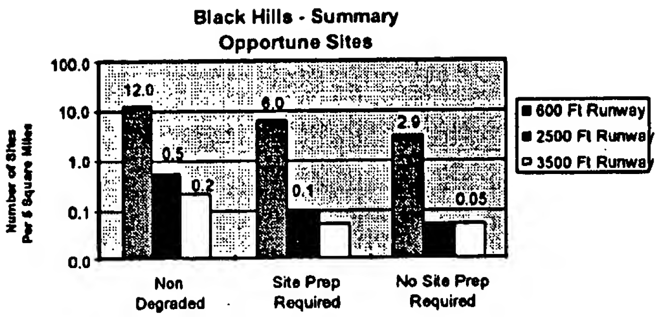
Table 2. Probability of Correct Selection

CATEGORY OF USEFULNESS	100-M	3-M	1-M	SITE SURVEY
Number of useful landing sites with or without preparation	8	4	4	4
Probability of Correct Selection	.5	1	1	NA
Number of useful landing sites not requiring site preparation	8	4	2	2
Probability of Correct Selection	.25	.5	1	NA

length. These metrics included: the number of opportune landing sites per Alpha area [a five square mile area adjacent to the Forward Line Own Troops (FLOT)]; the average distance from the FLOT to the closest landing area; and the percent of Alpha areas that are occupied by at least one opportune landing area.

BATC used 100-meter, 3-meter, and 1-meter multispectral data to determine the number of opportune landing areas in each of the three areas of interest for each of three different runway length requirements: 600 feet, 2500 feet and 3500 feet. The data is presented in terms of the number of landing sites per five square mile Alpha area. Since 20 Alpha areas are contained in each 100-square mile area of interest, the number of opportune landing areas in each area of interest can be determined by multiplying the number of sites per five square mile area times 20. Results are shown for three conditions: non-degraded; site preparation could be required; and site preparation is not required. The number of sites found within each condition was determined by degrading the number of sites found by the 100-meter data. The first condition represents the 100-meter data with a degradation of 1. The second and third conditions represent the 100-meter data with a degradation of 0.5 and 0.25 applied to the quantity of landing areas contained in each of the 20 Alpha areas. The number of sites for the "site preparation required condition" and the "no site preparation required condition" is consistent with the results of the 3-meter and 1-meter data, respectively. Sample results are presented graphically in Figure 3 for the Black Hills. A significant advantage is shown using 600 foot runways.

A comparison of the average distance from the FLOT to the closest landing area is presented graphically in Figure 4 for the Salinas area, which had the most



Note: The 2500 ft and 3500 ft "no site preparation" site is an airport with a 4200 ft runway located near Spearfish in Alpha Area #2.

Fig. 3. Number of Opportune Landing Sites Per Aircraft Type, The Black Hills

dramatic differences among the three areas of interest. The differences noted in the Salinas area are due to the high availability of 600 foot landing areas for all FLOT positions.

FINDINGS AND FUTURE INVESTIGATIONS

The concept of identifying and locating forward opportune landing areas based on quality spectral data is feasible. The selection should involve a step-wise process

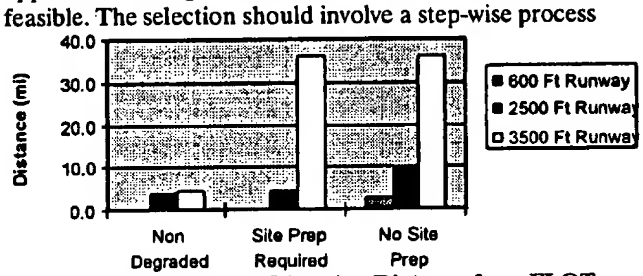


Fig. 4. Comparison of Average Distance from FLOT to the Closest Landing Area, Salinas, CA

beginning with the application of low-resolution spectral data as a first sort on a large area of interest and should gradually apply higher-resolution data to refine the initial estimate.

The 100-meter multispectral data is adequate to identify potential landing areas as a first sort. However, the 3-meter or 1-meter multispectral data is required to improve the probability of correct detection to an acceptable level. The use of level 1 Digital Terrain Elevation Data (DTED), which is the only DTED data available outside military intelligence channels, proved inadequate for discerning required slope variations. A finer slope measurement capability should be available from either 3- or 1-meter stereo pair images.

Ground hardness measurements (California Bearing Ratio) are limited by the spectral content of multispectral data. As a result, absolute values of CBRs were not determined in this study, although it was possible to provide discrimination over a range of CBR values. Hyperspectral data is expected to provide significant improvements to image texture analyses used for discerning object types and CBR values. Although this data is expected to be commercially available and affordable within the next several years, considerable data exists in the military intelligence community and could be made available to further expand on this application.

The number of "600-ft" opportune landing sites identified in all three geographical areas analyzed exceeded the number of conventional landing sites (2500- and 3500-foot) by more than a factor of twenty. However, a small percentage of those sites selected could be visited and evaluated, mainly because of economic reasons. More work is needed to further refine the process and to increase the sample size through more on-site visitations.

The findings of this study offer opportunities for significantly improving warfighting effectiveness and complement ongoing MDC efforts to show: 1) the timely airlift of key cargo items directly to a highly-mobile warfighting via opportune landing sites does impact battle outcome; and 2) combat airlifters can be designed and built to operate satisfactorily in and out of such landing areas. A parametric analysis of aircraft characteristics is continuing to determine optimal aircraft take-off and landing requirements.

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Words from the Internet Not Found in Our Dictionaries – Yet !!!

Neonphancy (ne on' fan see) n. A fluorescent light bulb struggling to come to life.

Phonesia (fo nee' zhuh) n. The affliction of dialing a phone number and forgetting who you were calling just as they answer.

Telecrastination (tel e kras tin ay' shun) n. The act of always letting the phone ring at least twice before you pick it up, even when you are only six inches away.

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User-centered design and evaluation of a real-time battlefield visualization virtual environment

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Abstract:
The ever-increasing power of computers and hardware rendering systems has primarily motivated the creation of visually rich and perceptually realistic virtu environment (VE) applications. Comparatively very little effort has been expe user interaction components of VEs. As a result, VE user interfaces are often designed and are rarely evaluated with users. Although usability engineering emerging facet of VE development, user-centered design and usability evalua as a practice still lags far behind what is needed. This paper presents a struct iterative approach for the user-centered design and evaluation of VE user inte This approach consists of the iterative use of expert heuristic evaluation, follo formative usability evaluation, followed by summative evaluation. We describ application of this approach to a real-world VE for battlefield visualization, de resulting series of design iterations, and present evidence that this approach cost-effective strategy for assessing and iteratively improving user interactior VEs. This paper is among the first to report applying an iterative, structured, centered design and evaluation approach to VE user interaction design

Index Terms:
data visualisation human factors military computing real-time systems user centred interfaces virtual reality cost-effective expert heuristic evaluation real-time battlefiel visualization realistic virtual environment rendering summative evaluation usability user interaction user interfaces user-centered design

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User-Centered Design and Evaluation of a Real-Time Battlefield Visualization Virtual Environment

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Abstract

The ever-increasing power of computers and hardware rendering systems has, to date, primarily motivated the creation of visually rich and perceptually realistic virtual environment (VE) applications. Comparatively very little effort has been expended on the user interaction components of VEs. As a result, VE user interfaces are often poorly designed and are rarely evaluated with users. Although usability engineering is a newly emerging facet of VE development, user-centered design and usability evaluation in VEs as a practice still lags far behind what is needed.

This paper presents a structured, iterative approach for the user-centered design and evaluation of VE user interaction. This approach consists of the iterative use of expert heuristic evaluation, followed by formative usability evaluation, followed by summative evaluation. We describe our application of this approach to a real-world VE for battlefield visualization, describe the resulting series of design iterations, and present evidence that this approach provides a cost-effective strategy for assessing and iteratively improving user interaction design in VEs. This paper is among the first to report applying an iterative, structured, user-centered design and evaluation approach to VE user interaction design.

Keywords: user-centered design, user interfaces, user interaction, user assessment, usability engineering, usability evaluation, virtual environments, virtual reality, expert heuristic evaluation, formative evaluation.

1 Introduction and Related Work

Despite the ever-increasing power of computers and hardware rendering systems, the user interaction components of VE applications are often poorly designed and are rarely evaluated with users. The vast majority of VE research and design effort has been on the development of visual quality and rendering efficiency. As a result, many visually compelling VEs are difficult to use and are, therefore, non-productive for their users. While these VEs might make good entertainment applications, their usability problems prevent them from being useful for efficiently solving real-world problems.

Usability engineering [10] and user-centered design [11] are newly emerging facets of VE design and evaluation. VE designers and developers are becoming aware of traditional human-computer interface (HCI) usability research and are beginning to apply and expand upon those methods for VEs. A few efforts have been reported to date; however, user-centered design and usability evaluation in VEs as a practice still lags far behind what is needed.

One reported work on user-based evaluation in VEs is Bowman et al. [1], who investigated an aspect of navigation in VEs and present a framework for evaluating travel (viewpoint motion control). The framework supports a methodology for evaluating different VE travel techniques and for appropriately matching travel techniques with virtual applications. Several aspects, or quality factors, were identified as being important to travel: speed, accuracy, spatial awareness, ease of learning, information gathering, presence, and user comfort. The authors acknowledge that task-related factors (task, environment, user, and system characteristics) can have a greater impact on quality factor performance than the travel technique selected. The evaluation methodology described is intended to be generalizable to a variety of VEs.

Salzman et al. [14] discuss how usability engineering methods shaped iterative development of a VE designed for educating students on various concepts associated with Newton's laws of physics. The goal of the design process was to develop a usable and educational virtual world. The authors applied usability evaluation to identify and refine early system weaknesses across three premises: usability, learning, and learning vs. usability. Both potential users (high school students) and experts in the field (physics professors) participated in the formative evaluations, which resulted in changes that improved the final VE user interaction.

Other research that has reported a limited element of usability evaluation includes a study of haptic interfaces [6], and an investigation of spatial input devices [7]. In addition, Stuart [16] describes basic methods for evaluating general usability components of VEs.

While these efforts provide insights about usability issues of specific VE technology, most do not provide sufficient breadth for large, complex VE design and assessment. Gabbard and Hix [4] propose a framework of usability characteristics structured to support usability engineering of VEs. They present a methodology for approaching design and assessment of VE user interfaces, which employs a top-down, step-wise refinement of VE usability space. This framework was used during evaluation of the battlefield visualization VE described herein (see Section 4.3 and Section 5).

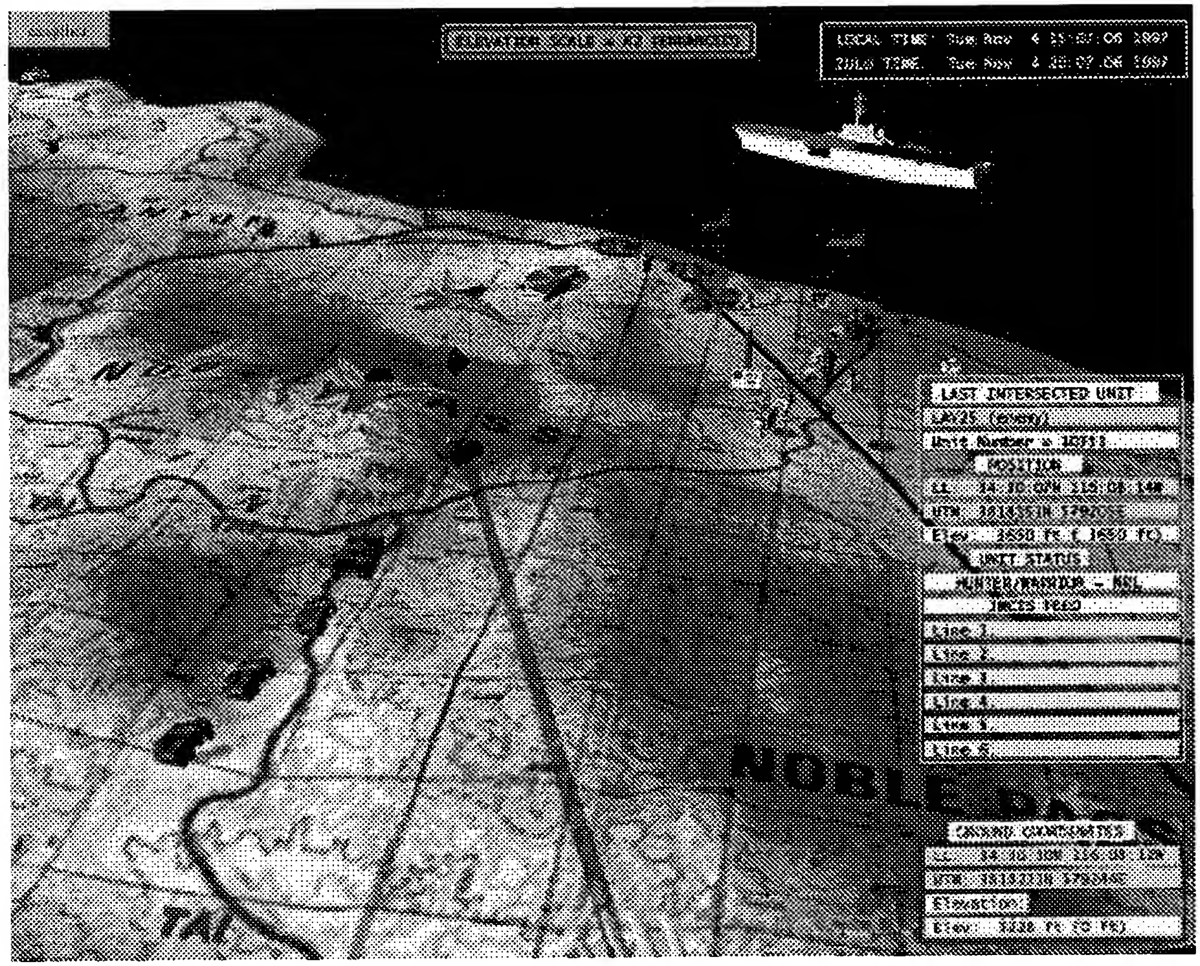

Figure 1: Screen shot from the Dragon battlefield visualization virtual environment.

Personnel at the Naval Research Laboratory's (NRL) Virtual Reality Lab have developed a VE for battlefield visualization, called Dragon (Figure 1) [3], which is implemented on a Responsive Workbench [9, 13]. The responsive workbench provides a natural metaphor for visualizing and interacting with three-dimensiona computer-generated scenes using a familiar tabletop environment. Applications in which several users collaborate around a workspace, such as a table, are excellent candidates for the workbench. Researchers from NRL, collaboratively with researchers from Virginia Tech, are empirically studying the most important usability parameters of an effective VE user interface for Dragon.

In the next section, we discuss battlefield visualization in general, and we describe the Dragon battlefield visualization VE. In Section 3, we discuss three important usability evaluation methods that can be profitably applied to VEs: expert heuristic evaluation, formative evaluation, and summative evaluation. In Section 4 we present our methodological approach for applying expert heuristic and formative evaluation methods to Dragon's design and evaluation, and in Section 5 we describe and discuss the design iterations that resulted from using this approach. In Section 6, we discuss lessons learned from this work, including evidence that our structured approach provides a cost-effective strategy for assessing and iteratively improving user interaction designs in VEs. We conclude with ideas for future work, particularly summative evaluation.

2 The Dragon Real-Time Battlefield Visualization Virtual Environment

2.1. Battlefield Visualization and Dragon

For decades, battlefield visualization has been accomplished by placing paper maps of the battlespace under sheets of acetate. As intelligence reports arrive from the field, technicians use grease pencils to mark new information on the acetate. Commanders then draw on the acetate to plan and direct various battlefield situations. Thus, the map and acetate together present a visualization of the battlespace. Using maps and overlays can take several hours to print, distribute, and update. Historically (before high-quality paper maps) these same operations were performed on a *sandtable* (a box filled with sand shaped to replicate the battlespace terrain). Commanders moved around small physical replicas of battlefield objects to direct battlefield situations. Currently, the fast-changing modern battlefield pro-

duces so much time-critical information that these cumbersome, time-consuming methods are inadequate for effectively visualizing the battlespace.

In Dragon, the workbench provides a three-dimensional display for observing and managing battlespace information shared among commanders and other battle planners. Visualized information includes a high-resolution terrain map; entities representing friendly, enemy, unknown, and neutral units; and symbology representing other features such as obstructions or key battle objectives. Dragon receives electronic intelligence feeds that provide constantly updated, displayable information about each entity's status, including position, speed, heading, damage condition, and so forth. Users can navigate to observe the map and entities from any angle and orientation, and can query and manipulate entities.

2.2. Design of User Interaction in Dragon

Early in Dragon's development, we developed and assessed three general interaction methods for the workbench, any of which could have been used to interact with Dragon: hand gestures using a pinchglove [12], speech recognition, and a hand-held flightstick. Although an interesting possibility for VE interaction, we found speech recognition still too immature for battlefield visualization, and we found the pinchglove to be fragile, time-consuming to pass from user to user, and limiting in that it requires right-handed users whose hands are approximately the same size. In contrast, we found the hand-held flightstick to be robust, easily handed from user to user, and applicable to both right- and left-handed users.

Based on these observations, we modified a three-button game flightstick by removing its base and placing a six degree-of-freedom position sensor inside. We tracked the flightstick's position and orientation relative to an emitter located on the front center of the workbench. We accomplished VE interaction with a *virtual laser pointer* metaphor: a laser beam appears to come out of the flightstick, allowing interaction with the terrain or object that the beam intersects.

Early in its development, when very little usability evaluation had been performed, Dragon was demonstrated as a prototype system at two different military exercises. In both demonstrations, an objective was a proof-of-concept for using a workbench-based battlefield visualization tool. Feedback from both civilian and military VIPs indicated that users found Dragon's battlespace visualization to be more effective and efficient than the traditional method of maps, acetate, and grease pencils. Following these successful demonstrations, we began intensive usability evaluations and iterations of Dragon's user interface.

3 Usability Evaluation Methods

User-based evaluation is an essential component of developing any interactive application, and is especially important for applications as complex and innovative as VEs. Three kinds of usability evaluation are particularly appropriate: expert heuristic evaluation, formative evaluation, and summative evaluation. We performed the first two types extensively during Dragon's development (Sections 4 and 5), and have plans for the third type (Section 6).

Expert heuristic evaluation [10] is a type of analytical evaluation in which an expert in user interaction design assesses a particular user interface by determining what usability design guidelines it violates and supports. Then, based on these findings, especially the violations, the expert makes recommendations for changes to improve the design. In the case of VEs, this is particularly challenging because there are so few guidelines that are specific to VE user interfaces. Thus, users are not directly involved in expert heuristic evaluation. Typically, this type of usability evaluation is more effective if the experts are not also developers of the user interaction design being evaluated. This was our situation: the first three authors of this paper, who were not involved with development of Dragon, did much of the expert heuristic evaluation described in Section 4.3.

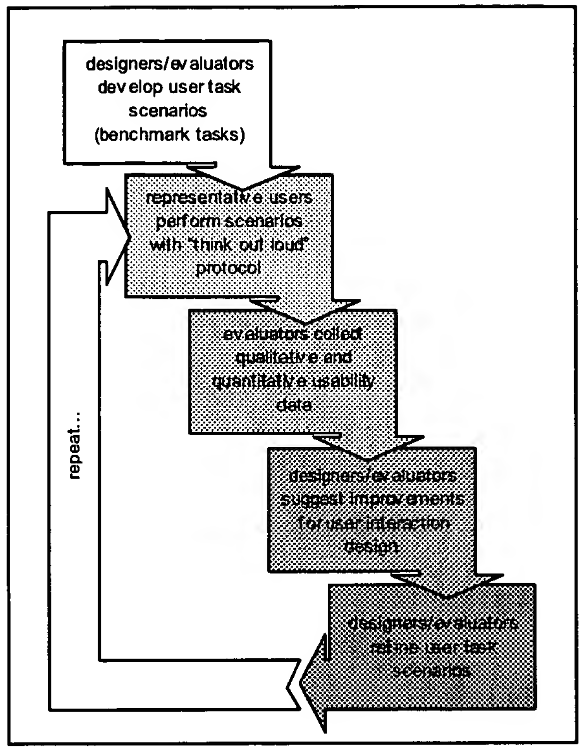

Figure 2: Formative evaluation process.

Formative evaluation [8] is a type of empirical, observational assessment *with users* that begins in the earliest phases of user interaction design and continues throughout the entire life cycle. Formative evaluation produces both qualitative (narrative) and quantitative (numeric) results. The purpose of formative evaluation is to iteratively and quantifiably assess and improve the user interaction design.

An important point to note in the formative evaluation process, shown in Figure 2, is that both qualitative and quantitative data are collected from representative users during their performance of task scenarios. Developers often have the false impression that usability evaluation is something rather warm and fuzzy, with no "real" process and collecting no "real" data. Quite the contrary is true; experienced usability evaluators collect large volumes of both qualitative data and quantitative data.

Qualitative data are typically in the form of *critical incidents* [5, 8]. A critical incident occurs while a user is performing task scenarios, and is an event that has a significant effect, either positive or negative, on user task performance or user satisfac-

tion with the interface. Events that affect user performance or satisfaction therefore have an impact on usability. Typically, a critical incident is a problem that a user encounters (e.g., an error, being unable to complete a task scenario, confusion, etc.). Section 5 describes the major design iterations that resulted from hundreds of critical incidents, which we collected during our formative evaluation studies.

Quantitative data are generally related, for example, to how long it takes and the number of errors committed while a user is performing task scenarios. These data are then compared to appropriate baseline metrics. Quantitative data generally indicate that a problem has occurred; qualitative data indicate where (and sometimes why) it occurred.

Collection of both these types of data is an important part of the formative evaluation process. While we focused largely on qualitative, critical incident data, we also collected some quantitative data.

Summative evaluation [8], in contrast, is an empirical assessment with users of an interaction design in comparison with other interaction designs for performing the same user tasks. Summative evaluation is typically performed when there are some more-or-less "final" versions of the interaction designs, and it yields primarily quantitative results. The purpose of summative evaluation is to statistically compare user performance with different interaction designs, for example, to determine which one is better, where "better" is defined in advance. Summative evaluations of Dragon are planned (Section 6).

Best guesses about an interaction design are substantiated or refuted by many tight, short cycles of heuristic and formative evaluation. During the design and assessment of the Dragon VE user interface, we performed numerous cycles of heuristic and formative evaluation—some as short as a few minutes (these were the really bad designs!), others lasting several hours. Evolution of essentially all decisions about design details came from many rounds of evaluation. As discussed in the following sections, from the heuristic and formative evaluations we have greatly improved Dragon's user interaction design, and are now planning a summative study.

4 Method: Application of Design and Evaluation Methods

4.1 Focus on Navigation

During our early demonstrations and evaluations, we observed that *navigation* — how users manipulate their viewpoint to move from place to place in a virtual world (in this case, the map for battlefield visualization) — profoundly affects all other user tasks. If a user cannot successfully navigate in a virtual world, then other user tasks (e.g., involving specific objects or groups of objects) simply cannot be performed. A user cannot query an object if the user cannot navigate through the virtual world to get to that object. Although we performed a user task analysis before our heuristic and formative studies, these studies corroborated our task analysis and our expectations of what tasks are most important.

Further, our observational studies revealed several other generic tasks performed by users of battlefield visualization VEs, including object manipulation, object selection, object querying, query response, and object aggregation. These user tasks will become the focus of possible future research for us and for others. Again, without having performed the expert and formative usability evaluations, we would only be able to guess at our assumptions about user tasks.

4.2 Methodology

We used the basic Dragon application as an instrumentable testbed, modified as needed for our heuristic and formative usability evaluation purposes. We performed extensive evaluations over a nine-month period, using anywhere from one to three users for each cycle of evaluation. From a single evaluation session, we often uncovered design problems so serious that it was pointless to have a different user attempt to perform the scenarios with the same design. So we would iterate the design, based on our observations, and begin a new cycle of evaluation. We went through four major cycles of iteration (Section 5).

Based on our task analysis and early evaluations, we created a set of scenarios comprised of benchmark user tasks, carefully considered for coverage of specific issues related to navigation. For example, some of the tasks exploited an ego-centric (user moves through world) navigation metaphor while others exploited an exo-centric (user moves the world) navigation metaphor (see Section 5). Some scenarios exercised various navigation tasks (i.e., degrees of freedom: pan, zoom, rotate, heading, pitch, roll) throughout the virtual map world. Other scenarios served as primed exploration or non-primed searches [2], while still others were designed to evaluate rate control versus position control in the virtual world. We thoroughly pre-tested and "debugged" all scenarios before presenting them to users during an evaluation session.

4.3 Expert Heuristic Evaluations

During our expert heuristic evaluations, various user interaction design experts worked alone or collectively to assess the evolving user interaction design for Dragon. In our earliest heuristic evaluations, the experts did not follow specific user task scenarios per se, but engaged simply in "free play" with the user interface. All experts knew enough about the purpose of Dragon as a battlefield visualization VE to explore the kinds of tasks that would be most important for users of Dragon. During each heuristic evaluation session, one person was typically "the driver," holding the flightstick and generally deciding what and how to explore in the application. One and sometimes two other experts were observing and commenting. Much discussion occurred during each session.

As mentioned earlier, the first three authors of this paper were often the experts assessing the current design. Their assessment and discussions were guided largely by their own knowledge of interaction design for VEs, and, more formally, by a framework for usability characteristics of VEs [4], discussed in Section 1. This framework provided a more structured means of evaluation than merely wandering around at random in the application, and provided guidance on how to make modifications to improve discovered design guideline violations. The major design problems uncovered by the expert heuristic evaluations were: 1) poor mapping of navigation tasks (e.g., pan, zoom, pitch, heading) to flightstick buttons, 2) missing functionality (e.g., exo-centric rotate, terrain following), 3) problems with damping of map movement in response to flightstick movement, and 4) graphical and textual feedback to the user about the current navigation task (e.g., pan, zoom, etc.). These problems, and

how we addressed them, are discussed further in Section 5. After our cycles of expert heuristic evaluation had revealed and remedied as many design flaws as possible, we moved on to formative evaluations.

4.4 Formative Evaluations

During each of six formative evaluation sessions, we followed a formal protocol of welcoming the user, giving them an overview of the evaluation about to be performed, and then explaining the responsive workbench and the Dragon application. We were careful to *not* explain too many details of the Dragon interaction design, since that was what we were evaluating. Then the user was asked to play with the flightstick to figure out which button activated which navigation task (e.g., pan, zoom, etc.). We timed each user as they attempted to determine this, and took notes on comments they made and any critical incidents that occurred. Once a user had successfully figured out how to use the flightstick, we began having them perform the scenarios. If about 15 minutes passed without a user figuring out the flightstick and its buttons (this happened in only one case), we filled in details that they had not yet determined and moved on to scenarios.

Time to perform the set of scenarios ranged from about 20 minutes to more than an hour. We timed user performance of individual tasks and scenarios, and counted errors they made during task performance (quantitative data). A typical error was moving the flightstick in the wrong direction for the particular navigation metaphor (exo-centric or ego-centric) that was currently in use. Other errors involved simply not being able to maneuver the map (e.g., to rotate it) and persistent problems with mapping navigation tasks to flightstick buttons. Again, these are discussed further in Section 5. We also carefully noted critical incidents, especially related to errors, and constructive comments users made about the design (qualitative data).

During each session, we had at least two and often three evaluators present: one was the "leader" who ran the session and interacted with the user; the other one or two evaluators recorded timings, counted errors, and collected qualitative data. While both the expert heuristic evaluation sessions and the formative evaluation sessions were personnel-intensive (with two or three evaluators involved), we found that the quality and amount of data collected by multiple evaluators greatly outweighed the cost of those evaluators. After each session, we analyzed both the quantitative and qualitative data, and based our next iteration on our results, as explained in the next section.

5 Results: Iterations of the Dragon User Interaction Design

Table 1 summarizes the four major iterations of the Dragon user interaction design over an approximately one-year period. It gives a high-level description of each iteration (including both visual and flightstick characteristics), and indicates the major usability findings for each iteration. (Space does not permit us to explain all the information in this table in detail.) Our findings, shown in rows of the table, fell into four categories:

General Description. For each iteration, we give a brief descriptive title in the top four cells of Table 1. A general description of each iteration's most salient features is shown beneath, along with the approximate date when the iteration was completed.

Interaction Description. This category describes some specifics of how a user interacts with each design iteration. We experimented extensively with variants of two different navigation metaphors (described below): exo-centric and ego-centric. We visualized the virtual laser pointer (see Section 2.2) by drawing a beam coming out of the flightstick and intersecting the environment. In the first ("Virtual Sandtable") iteration, we also drew a skeletal hand "holding" the beam to visualize the user's hand (lower edge of Figure 1). This category of Table 1 also shows the degrees of freedom used by the flightstick tracker.

Device Description. This category defines the mappings from the three flightstick buttons (left, right, and trigger) to degrees of freedom; examples are explained below.

Evaluation Results. This category indicates which evaluations were performed on each iteration, and summarizes major strengths and major flaws of each. The last row of Table 1 summarizes our user interaction design modification recommendations to Dragon's programmers.

During early design, we implemented two navigation metaphors: exo-centric (or map-centric) and ego-centric (or user-centric). An *exo-centric navigation metaphor* is based on how a user would interact with a real physical map on a table. Different buttons are used for navigation tasks such as pan, zoom, and pitch. The map mimics the motion of the flightstick, so that the map acts as if it is stuck to the laser beam; user movement of the flightstick in any direction causes the map to move in that same direction. The magnitude of a user's gesture controls the distance of the map's movement in the virtual world (this is also called *zero-order motion*). This means that, for example, when panning from side to side of a zoomed-in map, a user must make repeated panning gestures, each of which translates the map a distance equivalent to the length of the user's gesture.

An *ego-centric navigation metaphor* is loosely based on the concept of a user flying above the map as if in an airplane. Various button combinations are again used for navigation tasks. The magnitude of a user's gesture controls the velocity of the map's movement (also called *first-order motion*); for example, a user can fly from one side to the other of a zoomed-in map with a single gesture.

The first iteration, "Virtual Sandtable", was based on the sandtable concept briefly described in Section 2.1, and was the version demonstrated in the military exercises mentioned in Section 2.2. So in addition to expert heuristic evaluation, we had feedback from the demonstrations. A key finding of this iteration was that users wanted a terrain-following capability, allowing them to "fly" over the map. Based on observations of users interacting with maps in a combat center, we had initially thought that a battlespace visualization application only required an exo-centric navigation metaphor. In reality, the workbench-based Dragon creates a very rich environment, in which users can do much more than just move a map. They can actually experience the environment by visually sizing up terrain features, entity placement, fields of fire, lines of sight, and so forth. Exo-centric navigation worked well when globally manipulating the environment and conducting operations on large-scale units. However, for small-scale operations, users wanted the "fly" capability. The logical approach to designing this into Dragon was an ego-centric flying capability. We found that the mapping of flightstick buttons to navigation tasks shown in Table 1 (i.e., trigger and left button pressed simultaneously produced

combined pan and zoom; trigger and right button together produced combined heading and pitch) worked well for users.

In designing the second iteration, "Point and Go," we used the framework of usability characteristics of VEs [4] (see Section 1) to suggest various possibilities for an ego-centric navigation metaphor design, such as WIM [15] and eye-in-hand [17]. We ultimately designed a "point and go" metaphor, in which we attempted to avoid having different modes (and buttons) for different navigation tasks (pan, zoom, etc.) because of known usability problems with moded interaction. Further, we based this decision on how a person often navigates to an object or location in the real world; namely, they point (or look) and then go (move) there. Our reasoning was that adopting this same idea to ego-centric navigation would simplify the design and at least loosely mimic the real world. So in this iteration, a user simply pointed the flightstick toward a location or object of interest, and pressed the trigger to fly there. We found through our expert heuristic evaluation that the single gesture to move about was not powerful enough to support the diverse, complicated navigation tasks inherent in Dragon. Furthermore, a single gesture meant that all degrees of freedom were controlled by that single gesture. This resulted in, for example, unintentional rolling when a user only wanted to pan or zoom. Essentially, we observed a *control* versus *convenience* trade-off. Many navigation tasks (modes) were active simultaneously, which was convenient but difficult to physically control. With separate tasks (modes), there was less convenience but physical control was easier because degrees of freedom were more limited in each mode. In addition to these serious problems, we found that users wanted to rotate around an object, such as to move completely around a tank and observe it from all sides. This indicated that Dragon needed an exo-centric rotate ability, which was added. This interesting finding showed that neither a pure ego-centric nor a pure exo-centric metaphor was desirable; each metaphor has aspects that are more or less useful depending on user goals.

In the third iteration, "Modal," we went from the extreme of all navigation tasks coupled on a single button to a rather opposite design in which each navigation task was a separate mode. Specifically, as a user clicked the left or right flightstick button, Dragon cycled successively through the tasks of pan, zoom, pitch, heading, and exo-centric rotate. Once a user had cycled to the desired task, it was enabled and thus accessible from the trigger, and the task name appeared in a small textual indicator. We observed that, as we expected, it was very cumbersome for users to always have to cycle between modes, and it was obvious that we still had not achieved a compromise between convenience and control. Again using the framework of usability characteristics of VEs [4] for guidance, for our fourth iteration of the Dragon interaction design, "Integrated Navigation," we decided to couple pan and zoom onto the flightstick trigger, pitch and heading onto a single button, and exo-centric rotate and zoom onto the third flightstick button, as indicated in Table 1. Our fourth generation design appears to have achieved the desired convenience versus control compromise. In our final evaluation studies, we found that at last we had a design for navigation that seemed to work well for most users. The only problem we observed was minor: damping of map movement was too great and needed some adjustment, which we made.

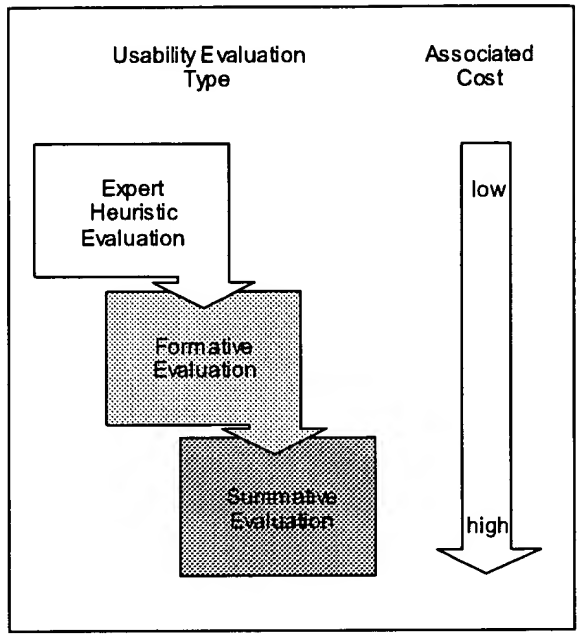

Figure 3: Types of usability evaluation and their cost.

6 Lessons Learned and Future Work

A key finding of our research is the successful progression from heuristic to formative to summative evaluations as a very cost-effective strategy for assessing and improving a user interaction design. Far too often, summative studies are conducted on applications whose interaction design has had little or no heuristic or formative evaluation. This situation is unfortunate because it is often the case that very expensive summative evaluations are comparing "good apples" with "bad oranges". That is, the differences between two interaction designs may occur because one design is inherently better, in terms of usability, than the other. If both designs have been heuristically and/or formatively evaluated, then experimenters can have confidence that the interaction designs are essentially equivalent in terms of their usability: they will be comparing "good apples" to "good oranges". And it is therefore much more likely that any differences found in a summative comparison are truly due to differences in the nature of the applications, and not in their user interaction designs per se.

Further, the cost of performing these three types of evaluations typically ranges from lowest for expert heuristic evaluations to highest for summative evaluations, as shown in Figure 3. So if expert heuristic evaluations are not performed prior to formative evaluations, the formative evaluations will typically take longer and require more users, and yet reveal many of the same usability problems that could generally have been discovered by less expensive heuristic evaluations. Thus, expert heuristic evaluations can reduce the cost of formative studies, and formative studies produce interaction designs that are truly comparable in summative studies for uncovering differences between applications.

	Virtual Sandtable	Point & Go	Modal	Integrated Navigation
General Description	sandtable metaphor	one gesture moves anywhere on map	all navigation tasks separated into discrete modes	modes mapped to all three flightstick buttons
Approximate Date	June 1997	November 1997	January 1998	April 1998
Interaction Description				
Navigation Metaphor	exo-centric (map-centric)	ego-centric (flying)	primarily ego-centric, except for exo rotate	primarily ego-centric, except for exo rotate
Laser Pointer Visual Representation	laser pointer & skeleton hand	laser pointer	laser pointer	laser pointer
Supported Degrees of Freedom	x, y, z, heading, pitch	x, y, z, heading, pitch, roll	x, y, z, heading, pitch	x, y, z, heading, pitch
Device Description				
Button Mappings	trigger & left→pan & zoom trigger & right→heading & pitch	trigger→pan & zoom & pitch & heading & roll	left and right buttons cycle modes: pan, zoom, pitch, heading, exo rotate	trigger→pan & zoom left→pitch & heading right→exo rotate & zoom
Evaluation Results				
Evaluations Performed	heuristic	heuristic	heuristic and formative	heuristic and formative
Major Strengths of Iteration	• easy to pan/zoom • good for overview tasks	• modeless navigation	• easy navigation to any location with single mode	• easy navigation to any location • easy to switch between navigation tasks
Major Flaws of Iteration	• skeleton hand orientation did not match user hand orientation • terrain following difficult • pan gesture parallel to floor not workbench screen	• hard to travel to non-visible location on map • could travel underneath map • trigger overloaded with too many degrees of freedom • many navigation tasks resulted in unintentional rolling	• too cumbersome to switch between modes	• too much damping; user movement too slow • zoom gesture parallel to workbench screen, not floor
Recommendations to Programmers for Interaction Design Changes	• support terrain following	• fine-tune damping and acceleration • add collision detection with map • remove ability to roll • add exo-centric rotation	• couple modes so that only three navigation modes because then can map to three buttons on flightstick • couple pitch and heading • couple pan and zoom	• fine-tune damping and acceleration

Table 1: Major iterations of Dragon user interaction design.

Our future work will focus on summatively evaluating our current navigation design. During our expert heuristic and formative evaluations, we discovered many different variables that affect navigation usability in VEs. We have narrowed this (initially large) list to five variables, based on the framework of usability characteristics [4], our observations during heuristic and formative evaluations, and our expertise in VE interaction design. We feel these five variables have the greatest effect on navigation, and are therefore the most important candidates for summative evaluations:

1) *navigation metaphor* (ego- vs. exo-centric),
2) *gesture control* (controls rate vs. controls position),
3) *visual presentation device* (workbench, desktop, CAVE™),
4) *head tracking* (present vs. not present), and
5) *stereopsis* (present vs. not present).

An expected result of these planned studies is empirically determined guidelines for navigation design in VEs.

To summarize, our research has produced results at three levels:

1) important navigation improvements in Dragon,
2) recommendations for navigation design in VEs, especially workbench-based VEs, and
3) evidential substantiation of a structured approach for user-centered design and evaluation of VEs.

This paper is one of the first to report using expert heuristic evaluation followed by formative usability evaluation as a structured approach to the iterative, user-centered design and evaluation of VE user interaction components. Our use of this approach with a real-world battlefield visualization VE has resulted in a VE for which we have empirical evidence of effectiveness and usability.

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Battlefield visualization on the responsive workben

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Index Terms:
command and control systems data visualisation virtual reality Dragon Hunter Warr
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Battlefield Visualization on the Responsive Workbench

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Abstract

In this paper we describe a battlefield visualization system, called Dragon, which we have implemented on a virtual reality responsive workbench. The Dragon system has been successfully deployed as part of two large military exercises: the Hunter Warrior advanced warfighting experiment, in March 1997, and the Joint Counter Mine advanced concept tactical demonstration, in August and September 1997. We describe battlefield visualization, the Dragon system, and the workbench, and we describe our experiences as part of these two real-world deployments, with an emphasis on lessons learned and needed future work.

Keywords: Battlefield Visualization, Responsive Workbench, Virtual Reality, Virtual Environments

1 Introduction

When fighting a battle, commanders must analyze and understand current and future combat situations in order to make good strategic decisions. This problem, which is as old as warfare itself, is referred to as ***command and control***. In addition, commanders must plan and evaluate possible future strategic force movements, an operation referred to as ***planning and shaping***. Currently, both activities are accomplished with paper maps of the battle area placed under sheets of acetate. Technicians receiving intelligence reports from the field depict the changing situation with grease pencils. Commanders may then plan various scenarios by drawing additional symbology on the map.

This is a cumbersome, time consuming process: detailed maps and overlays can take several hours to print and distribute. The fast-changing modern battlefield frequently produces so much time-critical information that the above manual techniques are inadequate for properly visualizing the battlespace. At the Naval Research Laboratory, we have developed a virtual-reality battlefield visualization system, termed ***Dragon***, which is implemented on a virtual reality responsive workbench. We have found the workbench to be an effective virtual reality interface for a battlefield visualization system.

In this paper we briefly discuss the battlefield visualization problem. We describe the workbench and review relevant work done to date. We follow this with a brief discussion of various design issues and tradeoffs we considered as we developed Dragon. We then describe using the system as part of two real-world, large-scale military exercises, and point out many of the lessons learned.

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2 Battlefield Visualization

Despite the advent of computers and sophisticated decision-making software in combat operation centers, the military still undertakes battlefield visualization predominantly with paper maps and acetate overlays. This is a hold-over from the days when reports from the battlefield arrived at the combat operations center exclusively by voice over a radio network. A radio operator at the center received the verbal report, and then translated the information into symbology that was hand-drawn on a paper map. Currently, this same data is sometimes entered by hand into a computer system, where it can be used by computerized battlefield visualization systems. Obviously this is a time-consuming process, with many opportunities for introducing error into the data stream.

New advances in distributed, encrypted digital data links allow combat units to report to the combat operations center using computer networks in place of voice radio links. The intelligence data is now available directly in a digital format. No time or manpower is wasted translating the data from voice report to computer input. Avenues for introducing error are also reduced to just the original reporter in the field. However, current combat operations centers do not take full advantage of this digital data. Time and manpower is spent monitoring this digital data stream and translating it into symbology on a paper map.

3 The Responsive Workbench

The Naval Research Laboratory's virtual reality responsive workbench [6, 10] provides a three-dimensional display for observing and managing battlespace information. The workbench provides a natural metaphor for visualizing and interacting with 3D computer-generated scenes using a familiar tabletop environment. Applications which traditionally require personnel to collaborate around a table are excellent candidates for using the workbench. Since 1994, the Naval Research Laboratory has successfully developed workbench-based prototype systems for medical planning and training [8], simulation based design, and battlefield visualization for planning and shaping as well as command and control [1, 9].

4 The Dragon System

The Dragon battlefield visualization system runs on a virtual reality responsive workbench. The system displays a three-dimensional representation of the battlespace (see Color Plates), which includes a terrain map, entities representing friendly, enemy, unknown, and neutral units, and symbology representing other features such as obstructions or key points in the plan of operations. Entities are represented both by schematic models as well as standard battlefield visualization symbols. Dragon receives electronic intelligence feeds which relate each entity's current status, including such information as position, current speed and heading, current damage condition, and so forth. As these reports are received, Dragon updates the corresponding models on the map. Users can view the

battlespace in either monographic or stereographic mode, and navigate to observe the map and entities from any angle and orientation. They can also query and manipulate the entities.

4.1 Interaction Techniques

A fundamental design decision for any virtual environment is how users navigate through the environment and interact with objects in the environment.

4.1.1 The Virtual Laser Pointer

The Naval Research Laboratory has developed three general interaction methods for the workbench: gesture recognition using a pinchglove [7], speech recognition, and a hand-held joystick. We considered using each of these as an input device for the Dragon system. Although an interesting avenue for virtual environment interaction, we deemed the speech recognition technology to be too immature for battlefield visualization. We also found the pinchglove problematic — it is fragile, time-consuming to pass from user to user, and only works for right-handed users whose hands are approximately the same size. In contrast, the hand-held joystick is relatively robust and very quickly handed from user to user, and works for both right- and left-handed users.

For the Dragon system we modified a three-button game joystick by removing it from its base and placing a six degree-of-freedom position sensor inside. The joystick's position and orientation are tracked relative to an emitter located on the front center of the workbench. The interaction metaphor for this joystick is a ***virtual laser pointer***. We imagine that a laser beam comes out of the front of the joystick and enters the virtual environment. Our system renders this beam as another virtual object (see Color Plate 3). Where the beam intersects the terrain or objects, a highlighted marker appears.

4.1.2 Navigation Metaphors Investigated

Using the virtual laser pointer as an interaction device, we implemented and field-tested two virtual environment navigation metaphors.

One metaphor, termed ***map-centric navigation***, was based on how users interact with a real physical map placed on a table surface. Various button combinations produce three navigation modes: pan, zoom, and pitch/yaw. For each mode, the map mimics the motion of the joystick. That is, the map acts as if it were attached to the joystick: a motion along a vector by the joystick causes the map to move by that same vector. For this metaphor the user makes a zero-order control gesture — that is, the magnitude of the user's gesture controls the ***distance*** of the virtual motion. This means that, for example, when panning from one side to the other of a zoomed-in map, the user must make repeated panning gestures, each of which translates the map a distance equivalent to the length of the user's gesture.

The other navigation metaphor we investigated, termed ***user-centric navigation***, was loosely based on the metaphor of a user flying above the map as if in an airplane. Various button combinations again produce three navigation modes: pan/zoom, pitch/yaw, and rotate/zoom. For the user-centric navigation the user makes a first-order control gesture — that is, the magnitude of the user's gesture controls the ***velocity*** of the virtual motion. This means that, for example, the user can fly from one side to the other of a zoomed-in map with a single gesture.

4.1.3 Object Manipulation

The user interacts with all entities on the map with the virtual laser pointer. The user selects an entity simply by pointing at it. Entity selection is denoted by drawing a blue wire frame sphere around the entity (see Color Plate 3). When an entity is selected, a window pops up on the right side of the workbench with all of the known information about that entity gathered from the system. By pressing a button on the joystick, the user can pick up a selected entity and move it around the virtual environment.

4.2 Models and Symbology

We use two different schemes for representing entities on the map (see Color Plates 2 and 3). For some entities we used Intelligence Preparation of the Battlefield (IPB) symbology [5]. This is a military-standard set of symbols representing both force units (e.g. companies of troops) as well as particular areas or locations (e.g. a *named area of interest* or a *targeted area of interest*). Since we needed 3D objects that were visible from oblique angles, we extruded the 2D symbols into cubes, and texture-mapped the symbols onto each face (for example, in Color Plate 2 the boxes marked with blue and red "x's" represent troop squads). For other entities, such as tanks, ships, and planes, we used realistic 3D models, both because we felt that an operator would be able to rapidly identify a realistic model based on shape and coloring, and because the IPB standard lacks symbology for specific pieces of hardware.

When rendered at a real-world size the entities all quickly became invisible as the user zooms away from the map (see Color Plate 1). Therefore, we provided a user-controllable scaling factor for all entities. In addition, most of the entities were represented at multiple levels-of-detail, which increased rendering efficiency. Finally, some entities supported multiple model versions representing variants on the basic chassis, such as a command variant, as well as various levels of damage.

Entity allegiance was multiply encoded using color, shading, and textures. Friendly units were lighter hued or blue in color and contained at least one American flag somewhere on the unit. Enemy units were darker or red in color and flew a skull and cross bones flag. Although to date the exercises where we have used the Dragon system have not required it, it is necessary to develop an additional encoding for unknown, neutral, and civilian units.

4.3 Data Feeds

Currently, the US military typically uses the Global Command and Control System (GCCS) [2] for collecting, storing, visualizing, and interacting with data coming from the field. This data is also occasionally translated into the Distributed Interactive Simulation (DIS) [4] format for use in military simulation systems such as the MODular Synthetic Armed Forces (MODSAF) system [11]. DIS systems are often used to simulate the outcome of a given situation and plan. Both systems provide position and status information for each entity in the battlespace.

Dragon can receive data feeds in both GCCS and DIS formats. Additional information, such as planning symbology, special enumeration of features, and hazards on the battlefield are hand placed by the user, either interactively or through a simple text file.

5 Lessons from the Field

The Dragon system and the workbench have been successfully deployed as a prototype system at two different military operations during the past year: the Hunter Warrior advanced warfighting experiment in March 1997 and the Joint Counter Mine advanced concept tactical demonstration in August and September 1997 [1].

The intent of the Hunter Warrior demonstration was to prove the potential of using a workbench-based battlefield visualization system to provide situational awareness as well as support for conducting planning and shaping operations. The workbench was po-

sitioned in the planning and shaping section of the combat operations center and used continuously to brief VIPs, both civilian and military. The commanders were very impressed by the ability to visualize the current operating picture accurately and efficiently on the workbench, especially when compared to the traditional but manpower- and time-intensive technique of using a paper map with acetate overlays.

The intent of the Joint Counter Mine demonstration was to showcase the potential of the workbench to another user community within the military that was concentrating their efforts on command and control of units in a highly congested operation area. For this exercise, the workbench displayed the ongoing simulation of new tactics and equipment for overcoming enemy mines.

5.1 Data Feeds

The GCCS-M system (the Marine variant of GCCS [2]) was used during the Hunter Warrior advanced warfighting experiment. Units in the field created digital report messages on Apple Newton personal data assistants, which in turn were linked back to the combat operations center by a radio wide-area network. The messages were parsed into a form that could be used by GCCS-M. The Dragon system received update reports from GCCS-M at regular intervals or upon user demand. Dragon parsed the GCCS-M data stream for unit type, positional data, and the last textual message sent from the unit (see Color Plate 3). Since the source of the GCCS-M information stream was from units in the field entering data, the data feed on individual entities was very irregular and sparse, resulting in "jerky" entity movements.

The DIS protocol [4] was used at the Joint Counter Mine demonstration. Although the data feed per unit was also irregular, because DIS contains a built-in protocol for dead reckoning, the entity movement was smoother and less distracting than it was at Hunter Warrior. This demonstrated that a workbench-based battlefield visualization system could also effectively provide situational awareness for a simulated military environment.

5.2 Interaction

We initially thought that a battlespace visualization system only required a map-centric navigation metaphor. We based this decision on our observations of how users interact with maps in the combat operations center. In reality, the Dragon system and workbench create a very rich environment in which users can do much more than just move a map. They can actually experience the environment by visually sizing up terrain features, entity placement, fields of fire, lines of sight, etc. Map-centric navigation worked well when globally manipulating the environment and conducting command and control operations on large-scale units. However, when small-scale operations were being examined, the operators wanted to be able to "fly" over the terrain and even get down to a first person viewpoint as if they were a person walking around on the ground. Map-centric navigation did not lend itself to conducting these types of operations in an intuitive way, which encouraged our development of the user-centric navigation metaphor.

The Dragon system lets the user select either a monographic or a stereographic view of the battlespace. In these exercises we observed that users chose the monographic mode much more often than the stereographic mode. We believe there are three main reasons for this: 1) the display technology currently only supports one (or at most two) stereo users, 2) stereo is fatiguing to the user, and 3) the environments for both military exercises were both relatively flat, and thus the improved depth perception from the stereographic mode was not as important as it may become in more geographically varied environments.

5.3 Visualizing the Battlespace

Displaying thousands of entities on a textured terrain map is a difficult visualization problem. In particular, it is difficult for a user to discriminate between various battlefield entities. Mitigating this problem has required experimentation, which has taught us several valuable lessons.

Camouflage: Many of our early 3D entity models had realistic camouflage texturing. Friendly units had lighter camouflage patterns and enemy units had darker camouflage patterns. This was often too subtle of a difference for differentiating between friend and enemy. In addition, the first terrain texture maps chosen contained a significant component of green, thus providing an ideal background for the camouflaged models to blend into. This, combined with the difficulty of picking appropriate model sizes, made it difficult to locate and identify the models on the terrain surface. One solution was to use a gray-scale texture map for the terrain. This highlighted the camouflaged models greatly, but reduced the ability to display terrain information using color as the discriminator.

Model Variation: There are usually multiple variations on a given military hardware entity. For example, an amphibious assault vehicle might come in a troop carrier configuration, a command and control variation, or an attack configuration complete with a light cannon. A battlefield visualization system must be able to visually differentiate between the different configurations of each entity. A related problem is that the ability to differentiate between entities can become difficult if the external appearance between two models is too similar. This calls for more modeling than we provided with Dragon, potentially with a standard model format that supports multiple variations within each model.

Scaling and Aggregation: There are obvious problems with attempting to display every individual entity in the battlespace. One solution is to aggregate individual units into larger hierarchical units [3]. Another solution is to scale the entities up as one zooms out, and down as one zooms in. However, scaling makes the aggregation problem even worse, as even distant entities will eventually intersect if one zooms out far enough. Further, the models will occlude the terrain beneath, and with a large size, it is difficult to ascertain a model's true position.

These are all very difficult visualization problems for which we do not yet have adequate solutions. Symbology, standard or new, may help with entity identification, scaling, and aggregation. However, it is critical that we do not transfer negative information. Any display metaphors must be thought out in detail and potential problems clearly documented and then understood by the user.

5.4 Impact on Battlefield Visualization

Visualizing the battlefield with the traditional paper map, acetate overlays, and grease pencils has served military commanders well for many years. However, the labor- and time-intensive procedures required to create and maintain these maps translate into expensive and out-of-date information being placed in front of the commander. In addition, the modern battlefield is producing ever more data at an ever-quicker rate. Finally, the modern combat operations center contains too many consoles displaying too much specialized information. The result is both information overload and information fragmentation. Clearly, traditional methods for battlefield visualization need to be improved.

GCCS-M is a partial solution to these problems. This system interfaces with some of the battlespace information gathering systems, and it does have the ability to display its results graphically.

However, the display is two-dimensional and is easily cluttered. We found the general opinion to be that the GCCS-M user interface is cumbersome and difficult to use.

The goal of Dragon is to improve battlefield visualization by using visualization techniques. In pursuing this goal we have extended battlefield visualization into three dimensions, represented entities by both symbolic and realistic three-dimensional models, displayed the results on a responsive workbench, and provided an intuitive interface for navigation and entity manipulation. We have also provided a system that integrates the output from several data feeds into a uniform representation presented on a single display surface. To date our field experiences suggest that Dragon is a superior battlefield visualization platform, compared to both the traditional map-with-overlay method as well as 2D battlefield visualization systems such as GCCS-M.

6 Conclusions and Future Work

Battlefield Visualization in the support of command and control as well as planning and shaping activities is a very difficult problem, but one that has potential for a large payoff. From our experience with Dragon we have come up with a number of areas for future work:

- It is necessary to conduct a formal task analysis to understand what different users in the combat operations center are trying to accomplish, how each task is currently accomplished, and finally how a visualization system can assist in accomplishing the tasks more quickly, with less manpower, and with a greater level of accuracy. A careful task analysis should identify key defaults that can be used to specify everything from how a query result should be displayed to what color scheme should be used.

- It is necessary to conduct user studies to investigate all the usability characteristics of the Dragon system, with an eye towards understanding user preferences and improving the user interface. Such a series of user studies is currently underway, with an emphasis on navigation techniques.

- Any battlefield necessarily deals with ***uncertainty***, and it is necessary to determine ways to represent and encode the confidence level that exists for each piece of battlefield data. For example, as the last reported position of an entity ages, the uncertainty of where the entity is currently located grows.

- Time must also become a part of a battlefield visualization system. This might be used to play back the previous 24 hours or to store and review the plans for the upcoming 24 hours.

- Distributed computing is the direction in which all military systems, but especially the Navy and Marines, are moving. This will include remote collaboration as well as distributing the work load across multiple platforms.

- The system must support more data feeds, including new as well as legacy systems. In the combat operations center there are still too many consoles with specialized users doing very narrowly defined tasks. Military commanders at the exercises we attended made it clear that a system capable of visualizing the output from a multitude of legacy systems in a single, consistent display and interface is desperately needed by today's combat forces.

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Airborne Battle Management System (ABMS)

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Abstract:
The Navy under the Airborne **Battle** Management System (ABMS) program, s by ONR Code 31 (Command, Control and Combat Systems) and executed by addressing the shifting focus of naval operations to power projection in a litto environment, as expressed in "Forward from the Sea" and "Operational Mane the Sea". To effectively project naval power into the littoral environment with reliance on a heavy footprint ashore, the force will require extensive NCW sup C4ISR located on the "high ground" provided by naval aviation. ABMS specific addresses the problem of "How to get the right information/**image**(s) to the r (s)/platform(s) soon enough?" in order to provide Navy and Marine Corps avi ability to observe, direct, and control from high above the littoral battlespace. central to our ability to respond quickly and accurately to **threats** deep inlanc employ ship-launched, air-launched, and ground-launched weapons with max

Index Terms:
command and control systems military aircraft military systems strategic planning ABMS Airborne Battle Management System Command, Control and Combat System U.S. Navy air-launched weapons battlespace ground-launched weapons littoral er naval aviation naval operations ship-launched weapons

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AIRBORNE BATTLE MANAGEMENT SYSTEM (ABMS)

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Abstract

The Navy under the Airborne Battle Management System (ABMS) program, sponsored by ONR Code 31 (Command, Control and Combat Systems) and executed by NAVAIR, is addressing the shifting focus of naval operations to power projection in a littoral environment, as expressed in "Forward from the Sea" and "Operational Maneuver from the Sea". To effectively project naval power into the littoral environment with minimal reliance on a heavy footprint ashore, the force will require extensive NCW support from C4ISR located on the "high ground" provided by naval aviation. ABMS specifically addresses the problem of "How to get the right information / image(s) to the right pilot(s) / platform(s) soon enough?" in order to provide Navy and Marine Corps aviation the ability to observe, direct, and control from high above the littoral battlespace. This will be central to our ability to respond quickly and accurately to threats deep inland and to employ ship-launched, air-launched, and ground-launched weapons with maximum effect.

ABMS provides the potential for substantial reduction in the engagement timeline for time critical and/or mobile targets through the development of and/or the integration of critical sensor-to-shooter and sensor-to-weapons technologies. Specifically, ABMS addresses Continuous Surveillance/Battle Damage Assessment, Sensor Management, Information Gathering & Management, Information Dissemination, Target/Combat ID, Multi-mission Coordination and Deconfliction, Dynamic ROE / ATO and other guidance, Targeting, Target / Weapon Pairing Rate, Flight Path Routing and Threat Avoidance, Precision Fire, Automated Distributed / Decentralized Weaponeering (C2), and Platform Survivability.

ABMS specifically addresses the problem of "How to get the right information / image(s) to the right pilot(s) / platform(s) soon enough?" by shortening the "Decide" phase of both the Detect, Decide, Engage and BDI/BDA Assessment aspects of the kill chain and the OODA (Observe, Orient, Decide, Act) loop. ABMS is three fold in that it is (1) developing and demonstrating the implementation concepts for intelligent in-flight 4-D (space – time) image management and dissemination, namely the "Image Editor" (Surveying/Anomaly Detection, Chicleting, IDing, & Filtering), "Router" (Selecting, Geo-Sorting, & Disseminating), and "Sorter" (Time-Sorting/Posting, Geo-Registering to 3-D Terrain Database, and Displaying when Relevant) for bandwidth / timeline reduction, (2) developing and demonstrating Automatic Target Cueing (ATC) and Combat Identification (CID) to recognize 3-D objects (discriminating between targets and friendlies / neutrals) and discriminating between 3-D objects and 2-D decoys, and (3) developing and demonstrating the "plug & play" system integration of a tactical airborne Network Centric information / image battle management and C2 architecture (which includes dynamic ROE, ATO, etc.), geo-registration software tools, various image processing software applications and ABMS' Image Editor/Router/Sorter.

Background

Naval aviation represents a unique resource beyond the evident use for sensing and strike. This is an element of the forward force with minimal distance to the enemy, minimal response time to threats (both offensively and defensively); location on a "virtual high ground" that can be as high as Mount Everest, and potential proximity to the enemy that is matched only by ground forces in close combat. Operational commanders have strived for centuries to capture the "high ground" as a location from which to observe, command, and control the battle, and naval aviation offers a significant potential to establish this advantage for our forces.

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These advantages are offset by obvious limitations in the ability to support warfighting functions in aircraft that can operate from bases afloat. Limitations include factors such as saturated workload for the pilots and small airborne staffs; limited bandwidth, processing, memory, and display resolution/definition; increased tempo/rate of change of the battlespace when conflict breaks out; and determining/providing functionally tailored information to the warfighters (what the warfighter needs) when they need it. Other issues include obtaining and integrating off-board and on-board information/images (I2), the need for immediately comprehendible information, "time-late" information, skin-to-skin architectural implications, etc., real-time (RT) node characteristics within the network-centric (NC) architecture for an embedded information management system (IMS) in the platform to manage sharing information (e.g., graphics & imagery, air/ground threats, retasking/replanning) with other forces to support a RT all-source I2 based sensor-to-C2-to-shooter picture of the battlespace, and affordability and retrofit issues (including shortfalls and architectural limitations of legacy aircraft). There is also the need to incorporate the architecture and infrastructure to produce an enterprise wide low latency tactical Single Integrated Battlespace Picture (SIBP). Another major issue is the absence of an integrated "plug & play" tactical airborne Network Centric I2 battle management and C2 architecture for the above critical sensor-to-shooter and sensor-to-weapons technologies.

Discussion

ABMS addresses these issues by a software development and implementation approach that is coordinated with preplanned software upgrades in the aircraft. One important software enhancement will address the current difficulty that Naval air assets have in sharing images that they collect during their respective missions. This is an important shortfall for time critical strike since tactical aircraft have the potential to share the most tactically relevant and lowest latency I2 and substantially reduce the timeline associated with the detection, decision, engagement and assessment of battle damage. An important technology area that the Airborne Battle Management System addresses is information management and dissemination, namely the processing and management to *automatically* handle the vast amount of data collected, and to *automatically* filter and disseminate the right information to the right operators at the right time. This includes merging of multimedia information as well as fragmenting massive files such as imagery to deliver the part(s) of the images that are relevant to the task.

One is forced to ask (since we can broadcast voice transmissions today): "Why can't we solve the problem of sending the right image to the right platform today?" A brute force approach does not work due to bandwidth overload. Existing demonstrations have essentially been limited to preplanned point-to-point transmissions.

A number of ongoing programs can be brought to bear immediately to provide near term enhancements.

The Advanced Aviation Subsystems (AAS) program, sponsored by ONR Code 35, has developed 3-D visualization technology making direct use of geo-specific databases and image base data. The principle functional product from AAS was used in Kosovo to provide targeting information from UAV (unmanned air vehicle) video in near real time. It provides the foundation for image exploitation and the Common Tactical Picture (CTP) by accurately geo-registering imagery and presenting it in a wider contextual view. In FY'00 and '01, the visualization and image registration capability will be implemented in embedded avionics processing hardware and then demonstrate these technologies in a time critical strike scenario.

The Real Time Execution Decision Support (REDS) Program was initiated by ONR to provide near real time retargeting capability and to expedite the processing and use of air tasking and air control plans. REDS has produced initial capabilities that are being used and evaluated onboard aircraft carriers and will transition to the future Joint Mission Planning System. REDS also processes the ATO and can deliver parsed, formatted data to the tactical control systems in aircraft such as the E-2C. REDS offers further potential to develop and upload planned route data in minute by minute snapshots for near real time deconfliction and airspace management.

The Automated Rules of Engagement (AROE) program initiated by ONR in FY99 will provide capability to automatically parse and process ROE messages. This will include a dynamic ROE an ATO database that will be linked to the tactical entities in the situation databases and will allow the operators to have a consistent and up-to-date view of the ATO and ROE implications on the threats. AROE offers an opportunity to offload a significant workload from the operators to this automation. Automated agents can provide further assistance by tracking ATO and ROE and providing cues and alerts to the tactical commanders and controllers and also to the higher level commands that are responsible for establishing the ATO and ROE.

Tactical Control System (TCS) is being developed to provide a wide range of control capabilities for UAVs. An airborne C4ISR control post is clearly a high value location to control low altitude UAVs deep in enemy territory since the links can be direct and relatively wideband and low latency. Proposed enhancements to this system to support time critical strikes will use advanced software to decrease the required footprint and operator-intensive workload and to make the system more amenable to operation onboard tactical aircraft that can operate from afloat bases. This could include both large fixed wing aircraft and VTOL aircraft such as the MV-22 or helicopters.

LARIAT 2, started in FY'00 is integrating the AAS visualization toolset into NAWCAD's Flying testbed, the Hairy Buffalo, and integrating on-board sensors and communication systems with AAS. Since AAS and the DARPA sponsored Warfighter Visualization program focussed on the EO and IR spectrum, LARIAT 2 will principally focus on the accurate registration of SAR imagery. Integration of SAR with highly accurate geo-specific data will provide an all weather strike capability.

The ONR ABMS program was initiated in FY99 to develop/demonstrate an affordable NC IMS and battle management / C2 architecture that supports the unique Naval Aviation C4ISR&T requirements for mission planning/replanning and to process/deliver/display RT tactically relevant I2 for RT targeting, air strike, and BDA/I. The integrated technology offers major improvements in time critical targeting, NC IMS, battle management and C2, aircraft survivability, and lethality through the use of advanced information technology to enhance the ability to differentiate targets using existing sensors, to support engagement/weapons release, to shorten the OODA loop, to improve real time situation awareness to avoid pop-up and air threats, to support rapid replanning of strike packages for time critical targets, to decrease fratricide and unintended collateral damage, to deconflict missions in the air and in the objective area on the ground, and to enhance the ability to dominate the battlespace.

ABMS supports the goals and objectives of the Navy Integrated Warfare Architecture (IWAR) by supporting several future Naval enabling capabilities and transition technologies in the areas of information superiority, power projection and air dominance. Furthermore, ABMS directly supports the ONR mission of developing supporting technologies and science and technology programs to provide such future Naval enabling capabilities. ABMS directly supports ONR's recent initiatives in Time Critical Strike while also supporting other ONR initiatives, e.g., Decision Support Systems, Autonomous Operations, Network Centric Warfare, Information Distribution, Missile Defense, and Platform Protection. In addition, ABMS supports ONR's mission of supporting several of the emphasis areas identified by Naval Aviation, e.g., Combat ID, ISR & Air-to-Ground Targeting, Network Connectivity, Tactical situation awareness (SA), EW/Defensive CM, Air-to-Ground Weapons, and Total SA.

Approach

To resolve the various issues identified above, ABMS is taking a three-fold approach: (1) development, application, and/or implementation of concepts for intelligent 4-D (space – time) in-flight multimedia information management for substantial bandwidth / timeline reduction and improved decision support, including where appropriate the integration of the ground picture with the air picture to create one SIBP; (2) system engineering analysis for implementation and integration of the ABMS concept into appropriate aircraft (E-2C, F/A-18, UAVs, MV-22, Marine Corps helicopters, etc.) to provide tactical airborne Network Centric battle management command and control capability (including determining what software elements are

needed / desirable in each platform) and (3) the Phase 2, laboratory demonstrations using simulations and flight demonstrations, to demonstrate the tactical utility of the ABMS concept. ABMS reduces the engagement timeline to minutes by the design, development and integration of its own technology with other existing and/or currently being developed technologies (i.e., AAS, REDS, AROE, TCS, LARIAT 2 and industrial efforts). Our approach is to develop the implementation concepts for intelligent in-flight 4-D image management and dissemination through software and perform the system integration of a "plug & play" tactical airborne Network Centric I2 battle management and C2 architecture for time critical sensor-to-shooter and sensor-to-weapons technologies. We will then demonstrate the ABMS architecture that enables shared airborne and surface platform information to Detect, Identify, Decide, Engage/Kill time critical fixed, mobile and moving targets while providing BDI/BDA in an all weather environment using multiple sensors and multiple existing (and/or new) communications links. The demonstrations will also show the use of that shared information for full SA for air/ground threat avoidance and for replanning consistent with the ATO and ROE. The transition products are (1) basically software upgrades (no new links, no new boxes, but will involve some new wiring) to provide the intelligent in-flight 4-D image management and dissemination, (2) an integrated "plug & play" tactical airborne Network Centric information / image battle management and C2 architecture, (3) airborne planning/replanning system, (4) theater wide cueing of imaging sensors, (5) automatic decision aids including dynamic ROE and ATO, (6) analysis of ATC/ATR alternatives, (7) analysis and dissemination of offboard land surveillance sensors (UGS), and (8) distributed weapons coordination and collaborative weaponeering of F/A-18s. The intelligent in-flight 4-D image management and dissemination portion of ABMS is a 6.2 research project and thus involves risk. Hence, in FY99 the "seed" ABMS program was established to mitigate this risk. The proof-of-concept 4-D intelligent image management and dissemination algorithm laboratory demonstration in early FY00 was successful in mitigating this portion of the risk. In addition, the ATC / CID laboratory demonstration in mid-FY00 was successful in mitigating this portion of the risk Likewise, both the intelligent in-flight 4-D image management and dissemination portion of ABMS and the ATC / CID as well as the integrated "plug & play" tactical airborne Network Centric information / image battle management and C2 architecture leverage other on-going ONR activities to further mitigate risk.

Description

ABMS is three fold in that it is (1) developing and demonstrating the implementation concepts for intelligent in-flight 4-D (space – time) image management and dissemination, namely the "Image Editor" (Surveying/"Hot Spot" Detection, Chicleting, IDing, & Filtering), "Router" (Selecting, Geo-Sorting, & Disseminating), and "Sorter" (Time-Sorting/Posting, Geo-Registering to 3-D Terrain Database, and Displaying when Relevant) for bandwidth / timeline reduction (Figure 1), (2) developing and demonstrating ATC and CID to recognize 3-D objects (discriminating between targets and friendlies / neutrals) and discriminating between 3-D objects and 2-D decoys (Figure 2 depicts the ABMS Concept), and (3) developing and demonstrating the "plug & play" system integration of an architecture for tactical airborne Network Centric information / image battle management and C2 (which includes dynamic ROE, ATO, etc.), geo-registration software tools, various image processing software applications and ABMS' Image Editor/Router/Sorter. The ABMS Functional Architecture is depicted in Figure 3 and the Program is depicted below in Figure 4.

ABMS substantial reduces the engagement timeline for time critical and/or mobile targets through the development of and/or the integration of critical sensor-to-shooter and sensor-to-weapons technologies. Specifically, ABMS addresses: Continuous Surveillance/Battle Damage Assessment, Information Gathering & Management, Information Dissemination, Deconfliction, Target/Combat ID, Targeting, Target/Weapon Pairing Rate, Precision Fire, Automated Distributed/ Decentralized Weaponeering (C2), and Platform Survivability.

Time Critical Strike (TCS) requires the capability to quickly transfer critical information among the various military forces. Even more important, however, is that the information which is

passed be relevant to the mission and that this relevance be made abundantly clear to the warfighter. Therefore, our methodology is to handle both the flow of critical information with its relevance and integrate this into the "plug & play" tactical airborne Network Centric information / image battle management and C2 system. Figure 5 depicts the ABMS low latency I2 flow and real-time execution control.

Through the "Image Editor", "Router" and "Sorter" of the intelligent in-flight 4-D image management and dissemination subsystem, the ATC / CID software and the in-flight, in-theater integrated "plug & play" tactical airborne Network Centric information / image battle management and C2 system the time critical targeting timelines are reduced and targeting accuracy is increased. Information will automatically be routed through the intelligent network and directed to those warfighters with an operational need for it. The information will then be presented in a manner tailored to the warfighter's needs. Since only a small portion of the information is likely to be relevant to individual warfighting components, the actual information / image flow necessary to accomplish this is much smaller than might be imagined. The quantitative benefit is a 100X to 10,000X improvement in the bandwidth / timeline to pass the image chiclets to the image analysts and / or warfighters. ABMS is an affordable solution in that it utilizes existing Data Links to provide an integrated tactical airborne Network Centric information / image battle management and C2 system which can provide one meter targeting accuracy through the use of a 3-D Digital Terrain Elevation Database. Figure 6 depicts our global vision of the Network Centric C4ISR&T Information Superiority Architecture and the CTP / COP – SIBP.

To solve these problems we were forced into a new paradigm, i.e. a "smart" approach that necessitates (1) innovative, intelligent RT 4-D (space-time) image management and dissemination utilizing logic, down-selection, determination of applicable user(s) and intelligent Image Editing, Routing, and Sorting. ABMS reduces the engagement timeline to minutes by this new paradigm and leveraging of other existing and/or current developing technologies. Our approach is to develop the implementation concepts for intelligent in-flight 4-D image management and dissemination and ATC / CID through software. ABMS performs the system integration of a "plug & play" tactical airborne Network Centric information / image battle management and C2 architecture for time critical sensor-to-shooter and sensor-to-weapons technologies.

Payoff

The ABMS expected payoffs are: (a) Timely processing of images (e.g. selects, filters, shares, routes, delivers, geo-registers) and display of low latency tactically relevant images for real-time targeting, air strike, BDI / BDA and (total and tactical) SA for a Common Tactical / Operational Picture (CTP / COP) and time critical targeting; (b) ATC / CID, (c) Handles both the flow of critical information and its relevance as well as managing the available limited network bandwidth (BW); (d) Shrinks the OODA cycle time by moving tactical functions from the rear-base to airborne platforms; (e) Provides GPS equivalent targeting through geo-registration of high quality image chiclets into a Digital Terrain Elevation Data (DTED) type 3-D data base; (f) Supports mission planning / replanning; (g) Anticipates threats (warning the pilots and decluttering cockpit displays), and (h) Provides an integrated "plug & play" tactical airborne Network Centric information / image battle management and C2 system for time critical targeting. In short, ABMS will ensure that the right information gets delivered to the right air platform at the right time and is presented / displayed when relevant.

Summary

ABMS will provide tactical flexibility through the implementation of technologies that will accelerate the transfer of useful information to the tactical warfighter and will integrate leveraging technologies to address existing shortfalls to improve the warfighters ability to prosecute re-locatable non-emitting targets (TBM, TEL, CCM), short dwell mobile intermittently emitting targets (TAC, SAM, IADS), and moving targets (tanks, APV, trucks). ABMS will provide the ability to discriminate between tanks, trucks, friendlies, neutrals and 2-D decoys. With 80% of the target set

mobile / re-locatable, ABMS will improve the Warfighter's reaction time by dynamically assessing the changed battlespace. ABMS will provide an affordable information manage and disseminate system that selects, processes and delivers the right information / images to the right platform at the right time and displays / presents it when relevant, shrinks the OODA loop cycle time, and provides a CTP / COP – a SIBP.

FIGURE 1: ABMS IMPLEMENTATION / CONCEPT: INTELLIGENT IN-FLIGHT 4-D (SPACE - TIME) IMAGE MANAGEMENT

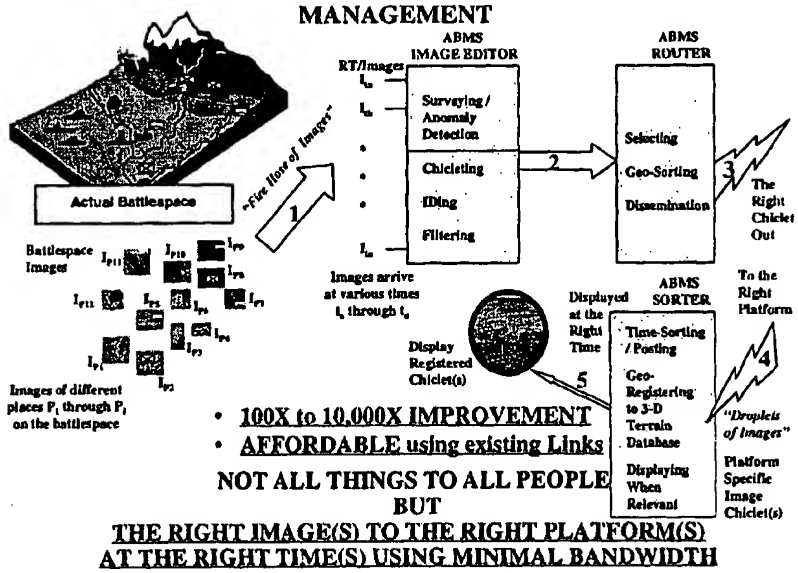

Figure 2 ABMS Concept / Example

I2 Disseminaton & ATC/CID

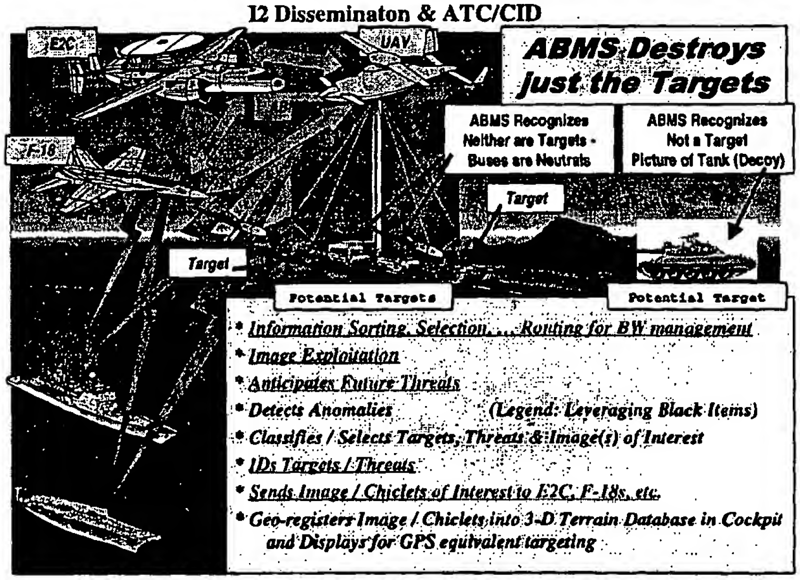

Figure 3
ABMS' Functional Architecture

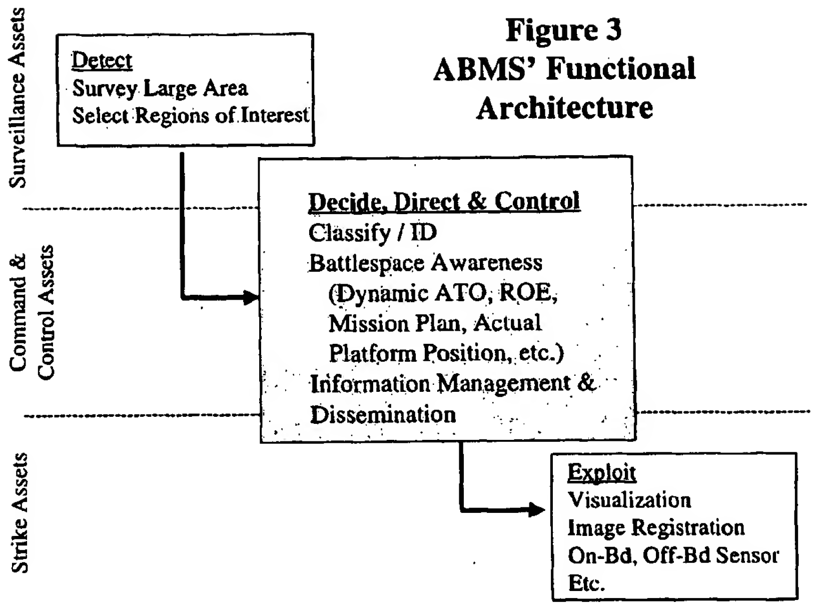

Figure 4 ABMS Program

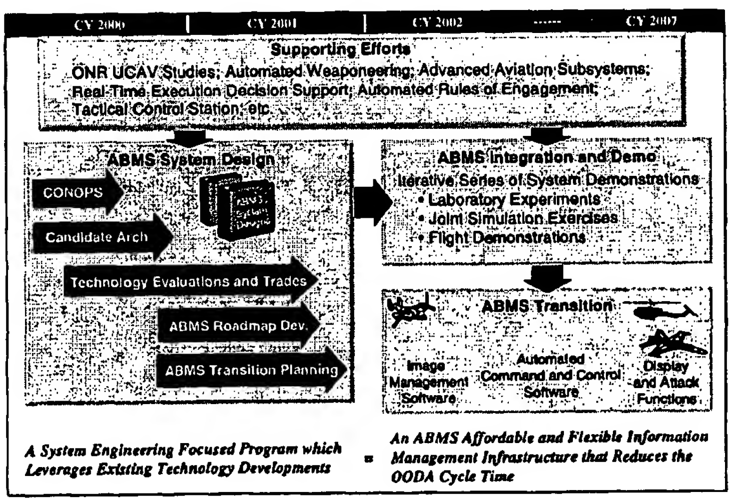

Figure 5: ABMS LOW LATENCY INFORMATION/IMAGE FLOW AND REAL-TIME EXECUTION CONTROL

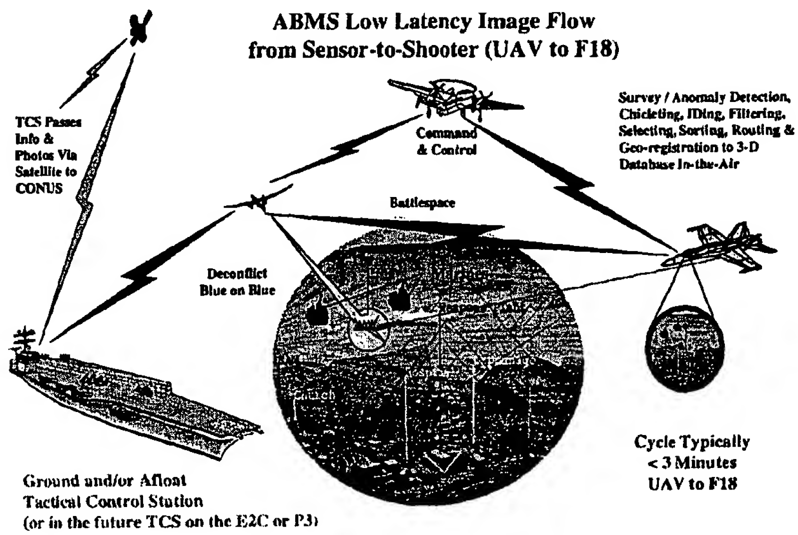

Figure 6: GLOBAL VISION - NETWORK C4ISR&T INFORMATION SUPERIORITY &